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Detection of Delaminations Below Asphalt Wearing Courses on Concrete Bridge Decks

Interim Report

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1/ INTRODUCTION

The detection of deterioration in concrete bridges with asphalt wearing courses is a difficult problem. Condition surveys, necessary to set priorities of repair, are currently carried out using the following procedures:

a/ delamination survey using a chain-drag technique;

b/ CSE half-cell testing to measure the corrosion potential of the reinforcing steel;

c/ selective coring and stripping of the asphalt wearing course to examine the concrete deck surface.

These tests do not guarantee an accurate assessment of the concrete condition. Deterioration such as scaling may go undetected due to the selective nature of the coring and stripping. The chain-drag technique cannot confirm the existence of delaminated or debonded areas without coring or stripping of the suspect areas. Complete removal of the asphalt wearing course is the only positive method of accurately determining the concrete condition; however, this procedure is not only expensive and time-consuming, it may also prove to be unnecessary. A reliable test procedure to ascertain the condition of an asphalt-covered, concrete bridge deck is needed.

2/ SCOPE OF THE PROJECT

The characteristics of a suitable test procedure were established as follows:

a/ The procedure should be independent of:
- concrete deck thickness;
- overlay thickness;
- climatic conditions excluding rain, snow, and freezing.

b/ The procedure should be applicable from the top surface of the deck as the underside is not always accessible.

c/ The procedure should be non-destructive.

d/ The procedure should be remote or non-contact in nature.

e/ The procedure should be accurate, consistent, and quick.

f/ The results should be both qualitative and quantitative.

To test various procedures, a bridge of known conditions was selected for use as a benchmark in determining the comparative results. This report discusses the test bridge condition, the preparation of the site, the procedures tested, and the results of the comparisons. Conclusions and recommendations for future work are included.

3/ TEST SITE

The test site selected for the assessment was an exposed concrete, thin slab on AASHTO beam structure. Built in 1968, the Papineau Creek Bridge is located on Highway 127, 2 km north of the Maynooth, Ontario. The bridge is 36.9 m long and 9.14 m wide with an area of 335.8 m^2. Prior to placement of a 75 mm asphalt wearing course, a condition survey was carried out to assess:

1/ the extent of delaminations and spalls;
2/ CSE half-cell potentials;
3/ depth of cover to reinforcing steel.

These procedures were carried out on a 0.5 m by 0.5 m grid to accurately assess the structure's condition. Descriptions of the test procedures are found in various publications [1, 2]. The results of the condition survey are shown in Figures 1, 2, and 3.

3.1/ Delaminations

A chain-drag technique and hammer sounding were used to outline the delaminations shown in Figure 1. The bridge has 21.25 m^2 or 6.4% of its area delaminated. Spalled areas amounted to 0.2% of the deck area. The delaminations were generally small in size, ranging from 4 cm in diameter to 0.5 m in width and 3.0 m in length. Generally, the delaminations were concentrated over the two piers with isolated delaminations in the rest of the deck.

Based on adjacent spalls, the delaminations ranged in thickness from 3 mm to 25 mm. Core samples were not taken as this would disturb the condition of the deck.

3.2/ CSE Half-Cell Potentials

A copper-sulphate electrode half-cell was used in accordance with ASTM standard C876-79 to measure the half-cell potentials. Although the potentials ranged from -0.07 V to -0.58 V (as shown in Figure 2), 62.3%

of the readings were <-0.25 V, indicating a 90% probability that corrosion was not occuring in those areas. This coincides with the small percentage of delaminated area.

3.3/ Cover

The depth of cover to reinforcing steel was measured using a James R meter. The results, shown in Figure 3, were variable, with a range of 17 mm to 44 mm. With the exception of two small spalls, no reinforcing steel was visible at the surface. It should be noted that the average cover depth of 31.8 mm is well below the present standard of 70 mm ± 20 mm.

4/ DECK PREPARATION

Prior to the placement of the two 38-mm thick courses of asphalt, thermocouples were installed in various locations. These are described in detail in Section 4.1. Two common forms of deterioration below asphalt wearing courses, scaling and debonding, were simulated and are described in Section 4.2.

The bridge deck was coated with asphalt cement and two 38-mm layers of asphalt were applied to the concrete surface. Prior to paving, the expansion joints were covered with a rubber membrane to prevent further ingress of moisture into the joint area. A waterproofing membrane was not applied to the deck.

4.1/ Thermocouples

A series of thermocouples were installed in the bridge deck to determine the heat flow in the deck. Figure 4 illustrates the location of the thermocouples; Table 1 describes their location. The thermocouples were used to determine if any temperature differences were found in the asphalt overlay over those areas which were delaminated, debonded, and scaled. Earlier work [3, 4, 5] has shown there is a temperature difference between sound and unsound concrete, with delaminated or unsound areas being hotter during daytime.

A series of T-type (copper-constantine) thermocouples were installed on top of delaminations and 5 mm into delaminations as well as the adjacent sound concrete. Five thermocouples were installed at various depths in the sound concrete. Additional thermocouples were installed between the two asphalt lifts over both delaminated and sound concrete. Thermocouples were also placed in the simulated scaling and debonding areas. Figure 5 shows an overhead view of the thermocouple layout and the areas of simulated scaling and debonding.

4.2/ Simulation of Scaling and Debonding

Scaling, the local flaking or peeling away of the near surface portion of

the concrete, was simulated by placing fine sand on the concrete surface prior to paving. Three areas, varying in size from 180 mm in diameter to 1050 mm by 625 mm, were set up adjacent to the curb (Figure 4). These locations were masked so that the asphalt-cement tack coat was not placed in the area. The masks were then removed, and the sand placed in the area. Figure 6 shows the sand in place after tack coating.

Debonding, the separation of the asphalt wearing-course from the concrete deck surface, was simulated by masking the concrete surface prior to the application of the tack coat (Figure 5). Prior to the paving, the masks were removed and the areas covered with thin layer of powdered talc. Laboratory tests indicated that a fine layer of talc would prevent the formation of a bond between the asphalt and the concrete. Two shapes, a circle and a triangle, were used in varying sizes ranging from 180 mm to 640 mm. Figure 4 shows the layout of these areas.

5/ TEST PROCEDURES

The following procedures were tested to assess whether they met the criteria discussed previously:

a/ chain-drag survey
b/ acoustic survey (Delamtec)
c/ ultrasonic survey (Pundit)
d/ seismic survey
e/ resistivity survey
f/ half-cell potential survey
g/ radar survey
h/ temperature survey
i/ infrared thermograph survey.

Each procedure was tested on a 0.5-m grid identical to the prepaving surveys. The procedures were assessed by comparing their results to the known areas of deterioration, and their ability to meet the criteria described in Section 2. A comparison summary for the techniques tested is found in Table 2.

5.1/ Chain-Drag Survey

The most common instrument used to detect delamination is a chain [6]. Figure 7 shows the chain being used on a bridge deck. The technician can detect a difference in sound as the chain strikes the sound and unsound areas of the deck surface. Some agencies use a sounding hammer; however, Stratfull [7] found that the chain will find delaminations not found with the hammer.

After paving, a technician with no prior knowledge of the deck carried out a chain-drag survey. Six small areas were identified (Figure 8). Five of these areas corresponded with known delaminations, although the areas identified tended to be smaller in size and rounder in shape. The sixth area was adjacent to the curb and may have been due to poor bonding of the asphalt overlay. In total, the five areas accounted for 0.5% of the existing delaminations.

The survey took roughly 1.5 h per lane, and closure of one lane was necessary. The method, while accurate on an exposed concrete surface, does not identify delaminations, or scaling accurately on asphalt-covered decks. The technician must make a subjective decision on the differences in sound, accounting for some inaccuracy. Overall, this procedure is not considered viable for use on asphalt-covered bridge decks.

5.2/ Acoustic Survey (Delamtec)

An acoustic survey was carried out using a Delamtec -- a portable, acoustic-sounding device developed by the Texas Transportation Institute [8, 9]. This instrument consists of three basic components: a pair of tapping devices, a pair of sonic transducers, and a two-channel pen recorder. Descriptions of the instrument can be found elsewhere [8]. The instrument is pushed along the deck at walking speed, and the two tapping devices strike the deck at a rate of 33 blows per second. The sonic transducers pick up the sound and generate electrical impulses which are amplified, filtered, and transmitted to the recorder producing pen deflections where delaminations are found. Computer programs analyse the trace readings to produce a scaled plot of the delaminations. Figures 9 and 10 show the Delamtec and its components during the field tests.

The instrument covers an area 76 cm wide with each pass, but only surveys 15 cm in the middle of the pass. Without numerous passes, some of the smaller delaminations are missed. Testing of this instrument on an exposed concrete deck has shown it to be less accurate than a chain-drag survey [3, 5]. While the Delamtec requires less than half the time taken with a manual chain survey, the possibility of missed information is greater. The technician must interpret the pen traces to input the data into the computer for plotting. This decision-making process could be overcome with the use of a tape recorder to record the information for electronic analysis of the data. The large amount of time currently spent on data reduction would also be decreased.

Two surveys of the asphalt-covered deck were carried out, and the results shown in Figures 11 and 12. Figure 11 shows the first survey results, with the actual delaminations shown in red. The computer assigned 10% of the deck area as delaminated. This is approximately 40% more delaminations than actually exist. After the instrument was adjusted, the deck was retested and the computer then assigned 1% of the deck surface as delaminated (Figure 12). This leaves roughly 85% of the existing delaminations undetected. A number of authorities have indicated that a thickness of asphalt greater than 25 mm masks the sound of the delaminations [2]. This may account for some of the inaccuracy in the test results.

It was noted that during the two tests, the calibration of the instrument is no different for exposed concrete surfaces as opposed to asphalt surfaces. The development of a calibration procedure specifically for asphalt-covered bridges would enhance the accuracy of the instrument. It is still necessary to core the discontinuities to confirm that the areas are delaminated, as the instrument cannot differentiate between delaminations and a lack of bond between the asphalt and the concrete.

The test procedure is weather-dependent as the electronic instruments are sensitive to moisture. Any water contained in delaminations or debonded areas will also give erroneous readings. In general, the procedure in its present form does not have sufficient accuracy to warrant its use on asphalt-covered decks.

5.3/ Ultrasonic Survey (Pundit)

Pulse velocity testing has been used since the mid-1940s to test the condition of concrete [10, 11]. Leslie and Chessman [10] used pulse velocity to evaluate internal cracking in concrete. The Pundit (Portable Ultrasonic Non-destructive Digital Indicating Tester) is a commercially available instrument developed from the early pulse velocity work. The instrument with its transducers is shown in Figure 13. The transducers use a 50 KHz frequency transmitting 10 pulses per second. The transducers were placed one on each side of the deck in the direct transmission procedure. Direct transmission is considered the preferred procedure [12] although Swift and Moore [13] found that the "timing-along

technique" or indirect transmission with both transducers on the same surface gave velocities in substantial agreement with the velocities obtained by direct transmission.

Initial testing was carried out on the Papineau Creek Bridge, in the curb area between stations 26A and 36A (Figure 1). This grid line covers the area of simulated scaling and debonding. The pulse velocities in km/s for the test line are given in Table 3. The velocities do not correlate with the areas of known deterioration. While one scaling area had a velocity of 2.91 km/s, another area known to be sound received a lower velocity of 2.53 km/s. Leslie and Chessman [10, 12] state that values between 2.1 and 3.0 km/s indicate poor condition concrete. The average value for the 10-m test area was 2.90 km/s. Based on Leslie and Chessman values, the velocities obtained do not correlate the known conditions.

Correction factors [12] for the effects of reinforcing steel temperature or moisture can be applied; however, the effect of the asphalt overlay has not been determined. The change in materials from asphalt to concrete may make the results unreliable.

A number of drawbacks were encountered during the testing:

1/ The majority of the bridge underside is over water and was, therefore, inaccessible. This made direct transmission impossible for most of the deck area.

2/ Variations in path length were inherent in the testing for a number of reasons. First, variations in the thickness of the asphalt overlay and the concrete deck could change the path lengths by ± 10%. Secondly, there is no guaranteed way to have the transducers directly opposite each other through the deck. Underside measurements are at best difficult if not impossible.

3/ Some areas of the deck could not be tested using direct transmissions due to the location of support beams on the underside. Approximately 12% of the deck area cannot be tested. It is significant to note that the majority of delaminations at Papineau Creek are located over the piers and are inaccessible for testing.

4/ Indirect, or "timing-along" testing, has poor results when the reinforcing steel is parallel to the direction of propagation of the pulse [12]. Correction factors are only considered approximate and therefore unreliable.

As a result of the poor initial test results and the drawbacks listed above, no further testing was carried out.

5.4/ Seismic Survey

Seismic refraction was used in the mid-1960s to monitor concrete condi tion beneath asphalt wearing courses. Phelps and Cantor [14] indicate micro-seismic refraction can be used to measure concrete thickness and indicate the condition of the concrete accurately.

A 12-channel Geometrics-Nimbus ES12-20 seismograph, commonly used in seismic studies of rock strata, was tested on the Papineau Creek Bridge. Figure 14 shows the seismograph and 12 geophones in field use. A 9-kg sledge hammer was used to generate the pulse. The time to reception at each geophone was then recorded by a 12-channel recorder. Two 10-m sections were tested, one in a sound concrete area, and the other in an unsound area. Figures 15 and 16 are typical traces for sound and unsound concrete, respectively. Although there is a difference between the two results, it was found impossible to pinpoint the location of any discontinuity. Seismic experts indicated that signal attenuation may be due to the support piers and beams as well as the reinforcing steel.

The test procedure was found to be very time-consuming. Moisture in the asphalt or between the asphalt and the concrete would also affect the results, although the field tests were carried out under hot and dry conditions. Further testing was considered unnecessary.

5.5/ Resistivity Survey

The ASTM standard test method ASTM D3633-77 for Electrical Resistivity of Membrane Pavement Systems [15], was used to assess its value in detecting concrete deterioration. The procedure is actually designed to measure the effectiveness of the membrane-pavement system. Descriptions of the

equipment and test procedure are found elsewhere [1,15]. The test is predicated on the fact that an electrical connection between the surface of the asphalt and the reinforcing steel in the concrete pavement cannot be made through an impermeable membrane. Figure 12 shows the test in progress.

Testing was carried out over a 4-h period in the south half of the northbound lane; an area 20 m by 5 m. The test results are plotted in Table 4. No correlation was found in the results between areas of sound and unsound concrete. The lack of correlation and the large amount of time required make this procedure inapplicable for use to detect concrete deterioration.

5.6/ Half-Cell Potential Survey

The use of a copper-sulphate half-cell as an indicator of corrosion activity in steel-reinforced concrete is well published [1, 7]. The test procedure is described in ASTM standard C876-79. When used on an asphalt-covered bridge deck, the asphalt overlay and associated waterproofing membrane must be penetrated so that an electrical contact can be made. Holes, usually 12 mm in diameter, are drilled to the concrete surface at set grid points. The holes are filled with a conductive solution and the half-cell test made.

Limited testing without drilling the above holes was carried out. The results (Figure 18) showed the asphalt overlay to have highly variable permeability. Sponges were used to soak grid points; however, full penetration of the wetting solution did not occur on every grid point. The half-cell potentials were on the low side in comparison to the prepaving potentials.

The half-cell test, while indicating a probability that corrosion is occurring, cannot be used to define the extent to which a bridge is delaminated or scaled. The method can only be used as an indicator of corrosion which may or may not have caused delamination.

5.7/ Radar Survey

High resolution, downward-looking radar was first used to detect deterioration in concrete bridge decks in 1977 [16]. Refinement of this initial work in 1980 produced credible results of 90% accuracy [17]. Details on the equipment and data analysis are found in reports by Cantor [17] and Alongi [18]. The systems described in the aforementioned reports were used to test the northbound lane of the Papineau Creek Bridge. The equipment was mounted on a hand-pushed cart (Figure 19). The deck was surveyed along the same grid lines used previously.

Figure 20 shows the radar signal for a sound portion of the deck, while Figure 21 shows the signal for a known delaminated section. On a grid-point basis, the radar picked up 86.6% of the locations which were delaminated or deteriorated. The operators had no knowledge of the deck condition prior to the survey. The radar system did, however, consider 98 additional grid points to be delaminated, which actually were not -- this lowers the overall accuracy of the system to 28.5%. Figure 22 shows the grid points considered deteriorated. The points which are delaminated are outlined in red. The radar also detected the simulated scaling in the curb area.

Discussions with the equipment manufacturers indicated that some modifications would improve the system's accuracy. The signals for this test were analysed by hand. Future work will be done using a magnetic tape recorder, thus allowing computer analysis of the test results [17]. While the cart-mounted equipment was used effectively, future work would have the system van-mounted [17], thus reducing test time because the bridge could then be surveyed at speeds up to 20 km/h.

The radar system meets most of the test criteria; the only exception is rainfall. The deck must be dry, as the radar will pick up any moisture within the deck and on the deck surface.

5.8/ Temperature Survey

The location, type, and number of thermocouples installed in the Papineau Creek Bridge are discussed in Section 4.1. Figure 23 shows the

temperature profile through the deck. This profile is similar to profiles obtained on exposed concrete decks [4, 5]. The asphalt wearing course acts as an insulator until 10:00. After this time, the temperature differences between the various depths begins to widen. Initially, there is very little difference in temperature between the area 25 mm into the concrete and the layer between the two lifts of asphalt. The deck surface temperature is 3°C warmer than the other layers.

A lag effect is seen between the temperatures, with the deck surface reaching a maximum at 15:30 while the maximum temperature in the concrete at 25 mm depth is not reached until 16:15. At the 100 mm depth, the concrete reaches its maximum at 17:00, one-and-a-half hours behind the deck surface.

The insulating effect of the asphalt is seen when comparing the temperatures of sound and unsound concrete to the temperatures between the asphalt lifts. At 09:00, the temperatures are equal with no difference between sound and unsound concrete. At 11:00, the unsound concrete is 3.5°C hotter than the sound concrete. Between the asphalt lifts, the termperature difference is only 0.7°C. Within an hour of the peak deck-surface temperature, the temperatures between the lifts over sound and unsound concrete are equal.

While temperature differences can indicate areas of deterioration, the use of thermocouples is time-consuming and undependable. They may also not be installed in deteriorated areas.

5.9/ Thermography Survey

Attempts were made as early as 1969 to use infrared thermography to detect delaminations in concrete specimens [19]. More recently, infrared thermography has been used to detect delaminations in exposed concrete bridge decks [3, 4, 5]. Two infrared systems were tested: the Agatronics 720 and the Flir 100. The Agatronics system consists of an infrared detection system using an IdSb detector with a spectral range of 2 μm to 56 μm, a CRT monitor, a 40° field of view lens, and a Polaroid

camera system coupled with a video tape data collection system. The Aga 720 system is an updated version of the equipment used on exposed concrete decks [4, 5].

The Flir (Forward Looking Infrared) system consists of an HgCdTe detector with a spectral range of 8 μm to 14 μm, a CRT monitor, and a video tape data collection system. Both the Flir and the Aga 720 have a temperature resolution of 0.1°C. The Flir system has superior spatial resolution, while the Aga 720 was found to have more thermal sensitivity.

Both systems were tested together at ground level, from an elevated boom, and from a helicopter at various altitudes above the bridge deck. Figures 24 and 25 show the systems in operation at the test site. The Aga system was also tested in its "Superviewer" configuration [4]. All infrared testing was carried out under weather conditions identified as optimum during the exposed concrete deck tests [5].

Good thermal images were not obtained until 11:30. The lag time in heat flow described in Section 5.8 was quite apparent with the scanner. No temperature differences were visible on the deck surface prior to 10:00, the point at which the solar heat reached the upper levels of the concrete. Testing continued until 15:30, at which point the deck surface temperature was at a maximum. After 15:30, the resolution of the thermal images deteriorated. The testing time-frame of 11:30 to 15:30 was found to be consistent for days when temperatures were in the 20°C range, with moderate cloud cover (<40%) and wind speeds of less than 25 km/h. During this time-frame, the scanner detected surface temperature differences between sound and unsound concrete ranging from 2°C to 3.5°C.

Figures 26, 27, and 28 are typical thermograms taken on the asphalt-covered surface. Figure 26 can be compared with the grid points 31-H in Figure 1; Figure 27 with grid points 28 to 26/J to P in Figure 1; and, Figure 28 with grid points 13 to 10/C to J in Figure 1. The delaminations appear as white or hot areas in the darker background. For convenience the delaminations have been outlined in Figure 26. The infrared scanner picks up 90% to 100% of the existing delaminations ranging in size from 5 cm in diameter to 0.5 m in width and 3 m in length. The shapes are consistent with those plotted before paving;

however, there is a tendency for the outlines to be "softer" in shape. This is most likely due to dissipation of heat in the asphalt layer.

As found in earlier work, the scanner picks up line markings as seen on the right side of Figure 28 and the left side of Figures 26 and 27. The influence of texture changes in the asphalt surface is visible in Figure 28 with a lighter area located in the centre of the lane -- an area of little polishing as it is between the wheel paths.

The scanner has been used from the elevated boom for mobile inspection of the deck at speeds up to 20 km/h. The hard copy images shown in Figures 26 to 28 were taken from the CRT on a video tape replay after testing. Mobile testing eliminates the need for lengthy lane closures. Airborne testing was found to be beyond the capability of the equipment as air safety regulations require a 300 m minimum altitude and the spatial and thermal resolution of the scanners at that height was adequate only for very large delaminations.

The viewing angle of ground level testing was found to be too sharp. The delaminations were poorly defined, and there was some interference by reflected radiation from the deck surface. An optimum height range of 4 m to 6 m was found to give the best definition of delaminated areas with the least interference from reflected radiation.

Tests were carried out with the scanner mounted vertically over the deck. The resultant image from a 4 m height (camera to ground) covered the 4 m lane width and a horizontal distance of roughly 4 m. Figure 29 is a vertical image of grid points 31 to 35/J to P. The dark line across the top of the image is the painted lane marker; i.e., the traffic is moving across the image from right to left. No advantage was found with the vertical image; however, production of a thermal image mosaic could be achieved with this procedure. Radial distortion of the images would create some problems in scaling the mosaic.

Computer analysis of the video tapes taken on the deck has shown that quantification of the delaminated areas is feasible. Some minor modifications of the vertical scanning mode would be necessary. These include stop-framing of the image either electronically or by physically

stopping the vehicle on the deck to allow roughly 30 s for the tape to be recorded in one position. This is the amount of time required for the computer to scan the image and analyse the data.

6/ SUMMARY

In most cases, the procedures tested at Papineau Creek were non-destructive and were used on the upper surface of the deck (only the Pundit testing was done from the underside of the bridge). Beyond these two criteria, the procedures differ vastly. Table 2 summarizes the procedures in terms of the criteria for a test method to detect deterioration in bridge decks with asphalt overlays.

Deck and overlay thickness influenced the results achieved with the seismograph, the Pundit, and the Delamtec. (Interpretation of the impact of overlay thickness was not made due to a lack of available expertise in this type of testing.) The time taken to carry out resistivity testing is greater with increasing overlay thickness.

Excluding freezing and rain, weather is a factor only in thermography. Thermography requires the sun to heat the deck. All other procedures are independent of weather.

Speed of testing varied with each method. The Delamtec, radar, and thermography are considered to be the fastest methods with vehicle-mounted testing of radar and thermography taking the least time. The latter two procedures were the only non-contact or remote procedures used.

All of the procedures tested are considered to be qualitative tests which will indicate the condition of the deck. The Delamtec and thermography are also quantitative tests. Both procedures give an indication of the extent of the deteriorated area. The Delamtec with a computer can produce a plan of the delaminations as well as a measure of quantity. The hard copy, thermal images can be pieced together to produce a photo mosaic of the deck surface. Computer analysis of the thermal images can produce quantitative measurements of the delaminated areas.

Radar and thermography were the most accurate test procedures. They both identified the majority of the delaminations; however, radar was the only procedure to identify the simulated scaling areas. Thermography has the

advantage of showing the area of delamination as opposed to a point of information given in the radar trace.

With careful work, the radar can be used to determine the boundaries of the delaminations; however, this eliminates a mobile test at 20 km/h and necessitates a lane closure for the work to be done.

Overall, the thermography had an accuracy of 83% in detecting deterioration below the asphalt wearing course at the Papineau Creek bridge site.

An additional demonstration test using thermography was carried out on the Nith River Bridge on Hwy 401 westbound near Kitchener. Using a mobile configuration (Figure 25), the bridge was scanned in roughly 15 min. Seventeen locations were identified as being delaminated. Of those 17 areas, ranging in size from 10 cm in diameter to 40 cm^2, 12 were selected at random; the 12 sites had temperature differences greater than 2°C. Each location was cored using a 10 cm diameter core bit. Ten of the twelve cores exhibited signs of deterioration. Seven cores were found to be delaminated with rust staining evident (Figure 30). Two cores showed evidence of scaling on the concrete surface (Figure 31). One core showed apparent debonding of the asphalt from the waterproofing membrane. The two remaining cores showed no evidence of deterioration. Temperature differences may have been due to textural differences on the asphalt surface resulting in a difference in emissivity and reflectivity.

7/CONCLUSIONS

1/ The Delamtec, radar, and thermographic methods can identify delaminations under asphalt wearing courses.

2/ None of the procedures tested meet all the criteria suggested for a test procedure.

3/ Radar and thermography hold the most promise for a test method to determine conditions of the concrete in a remote, inexpensive, and accurate fashion.

4/ Thermography offers the capability of producing scaled plans, accurately outlining the extent of deterioration below the asphalt wearing course.

5/ Improvements in data reduction and analysis systems are required before radar or thermography become more than a quick inspection tool to set priorities for detailed condition surveys.

8/ RECOMMENDATIONS

1/ Further demonstration tests using thermography and radar are recommended on bridges being waterproofed and paved in the 1982-83 fiscal year.

2/ Selective coring of the Papineau Creek Bridge should be carried out to complete the physical confirmation of data obtained by the various test methods.

9/ REFERENCES

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[4] Holt, F. B., and Manning, D.G., "Infrared Thermography for the Detection of Delaminations in Concrete Bridge Decks," presented at the Fourth Biennial Infrared Information Exchange, St. Louis, Mo., 1978.

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[6] Van Daveer, J.R., "Techniques for Evaluating Reinforced Concrete Bridge Decks." Journal of American Concrete Institute, Vol. 72, 1975, pp. 697-703.

[7] Stratfull, R.F., "Experimental Cathodic Protection of a Bridge Deck," Transportation Research Record No. 500, Transportation Research Board, Washington, D.C., USA, 1974, pp. 1-15.

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[9] Moore, W.M., "Detection of Bridge Deck Deterioration," Highway Research Record No. 451, Transportation Research Board, Washington, D.C., 1973, pp. 53-61.

[10] Leslie, J.R., and Chessman, W.J., "An Ultrasonic Method of Studying Deterioration and Cracking in Concrete Structures," Journal of the American Concrete Institute, Vol. 46, 1950, pp. 17-36.

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[13] Swift, G. and Moore W.M., "Investigation of Applicability of Acoustic Pulse Velocity Measurements to Evaluation of Quality of Concrete in Bridge Decks," Highway Research Report 378, 1972, pp. 29-39.

[14] Phelps, J.M., and Cantor, T.R., "Detection of Concrete Deterioration Under Asphalt Overlays by Microseismic Refraction," presented to the 45th Meeting of the Highway Research Board, Washington D.C., 1966.

[15] Electrical Resistivity of Membrane-Pavement Systems, ASTM Standard D3633-77.

[16] Cantor, T.R., and Kneeter, C.P., "Radar and Acoustic Emission Applied to the Study of Bridge Decks, Suspension Cables and a Masonry Tunnel," Report No. 77-13, Port Authority of New York and New Jersey, 1977.

[17] Cantor, T.R., and Kneeter, C.P., "Radar as Applied to the Evaluation of Bridge Decks", presented to the Transportation Research Board Meeting, Washington, D.C., 1982.

[18] Alongi, A.V. et al, "Concrete Evaluation by Radar Theoretical Analysis," presented to the Transportation Research Board Meeting, Washington, D.C., 1982.

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Table 1/ Thermocouple Locations

THERMOCOUPLE	LOCATION
1	Ambient air
2	Concrete surface, adjacent to delamination
3	Concrete surface, solid concrete adjacent #2
4	5 mm into solid concrete adjacent #3
5	5 mm into delamination adjacent #2
6	25 mm into solid concrete, installed in one hole
7	50 mm into solid concrete, installed in one hole
8	75 mm into solid concrete, installed in one hole
9	100 mm into solid concrete, installed in one hole
10	150 mm into solid concrete, installed in one hole
11	Centre of debonded area 600 mm, on concrete surface
12	Over delaminated area between 40-mm asphalt lifts adjacent #2, 5.
15	Over solid concrete between 40-mm asphalt lifts adjacent #3, 4.

Table 2/ Summary of Tests

TEST PROCEDURE	NON-DESTRUCTIVE	INDEPENDENT OF DECK/OVERLAY THICKNESS	INDEPENDENT OF WEATHER	SURFACE ONLY	REMOTE	SPEED	RESULTS
Chain Drag	Yes	Yes/Yes	Yes	Yes	No	Slow	Poor except large debonded areas. Plotted by hand.
Acoustic-Delamtec	Yes	Yes/No	Yes	Yes	No	Fast	Fair, needs calibration procedure. - computer analysed
Ultrasonic-Pundit	Yes	No/No	Yes	Yes/No *	No	Slow	Poor - numerical result
Seismic	Yes	No/No	Yes	Yes	No	Slow	Poor - unable to translate results
Resistivity	Yes	Yes/No	No (rain)	Yes	No	Slow	Poor - numerical result
Half-Cell Potential	Yes	Yes/No **	No (rain)	Yes	No	Slow	Poor - numerical result
Radar	Yes	Yes/Yes	Yes	Yes	Yes	Fast	Good - areas can be defined - computer assisted
Thermography	Yes	Yes/Yes	No (sun)	Yes	Yes	Fast	Good - graphic display of areas - computer assisted quantities

* Direct Transmission/Indirect Transmission

** Delay in Readings if no holes drilled

TABLE 3/ Pundit Results -- Direct Transmission

GRID POINT	VELOCITY (km/s)
26/A	3.19
26.5/A	3.00
27/A	2.72
27.5/A	2.53
28/A	2.98
29/A	3.05
30/A	3.07
31/A	2.81
32/A	2.91
33/A	3.00
34/A	2.98
35/A	2.64
36/A	2.87

MATERIAL LIST			
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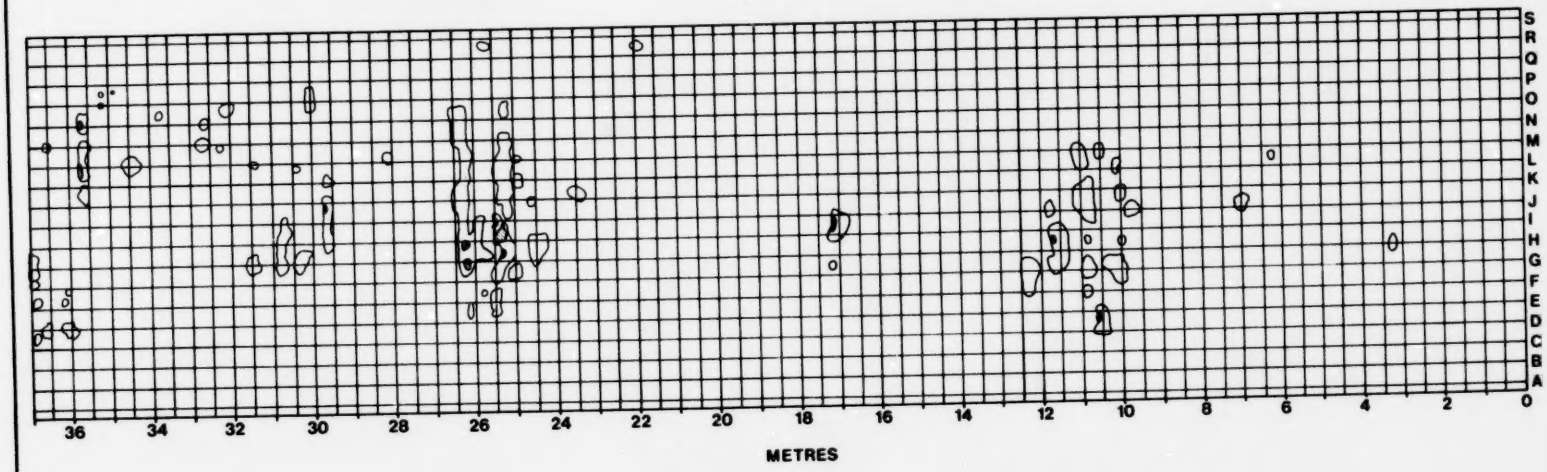

Figure 1/ Delaminations

Ontario Ministry of Transportation and Communications	ENGINEERING RESEARCH AND DEVELOPMENT BRANCH	SCALE	1.5 cm-1 m
		DATE	
		DRAWN	
		TRACED	
		CHECKED	

TOLERANCES: DECIMALS, ANGLES, FRACTIONS

LET	DESCRIPTION	DATE	BY
	REVISIONS		

Spall

Pre-Paving Condition
PAPINEAU CREEK BRIDGE

DRAWING NUMBER
OF
PROJECT NUMBER
22114

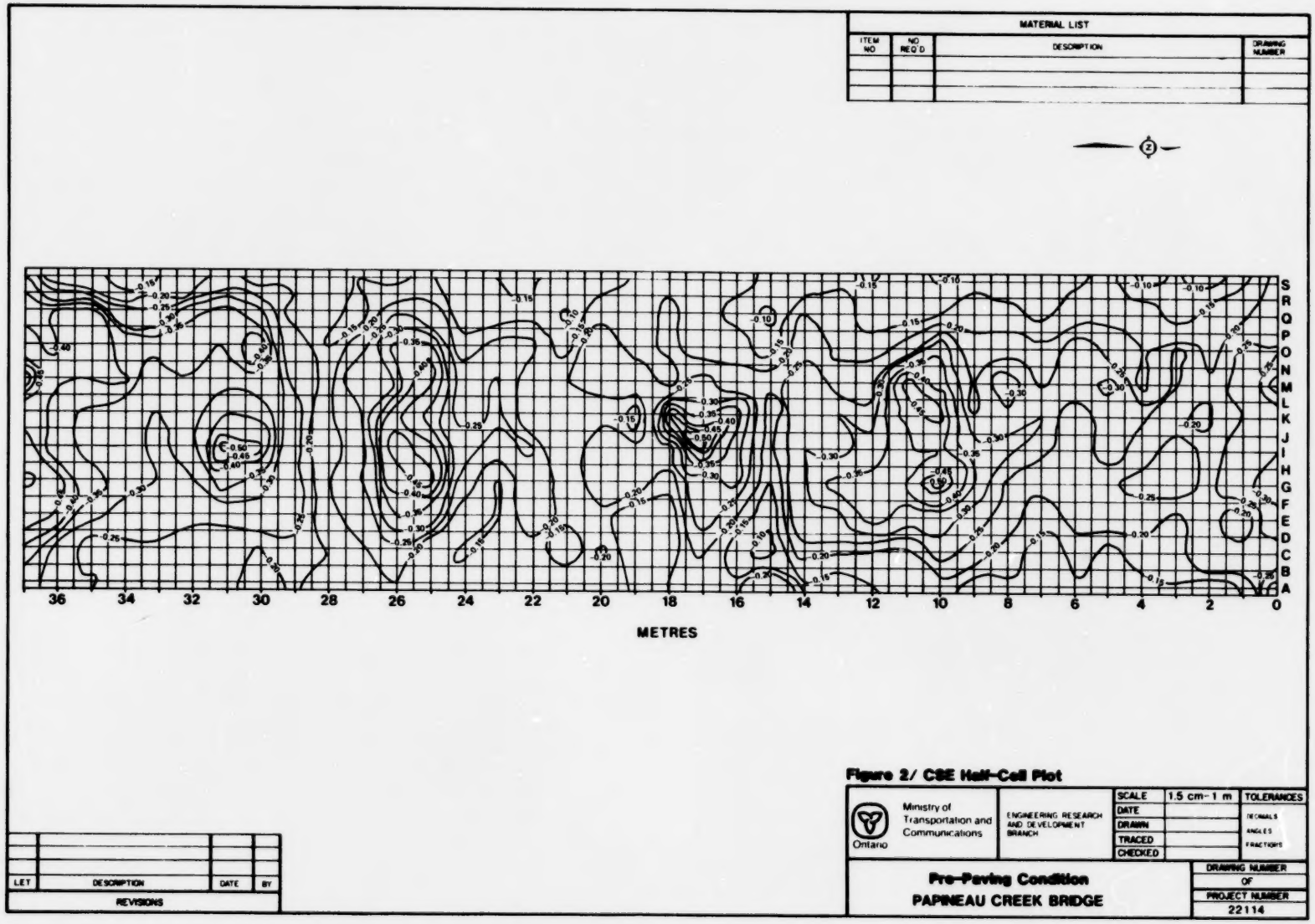

Figure 2/ CSE Half-Cell Plot

MATERIAL LIST			
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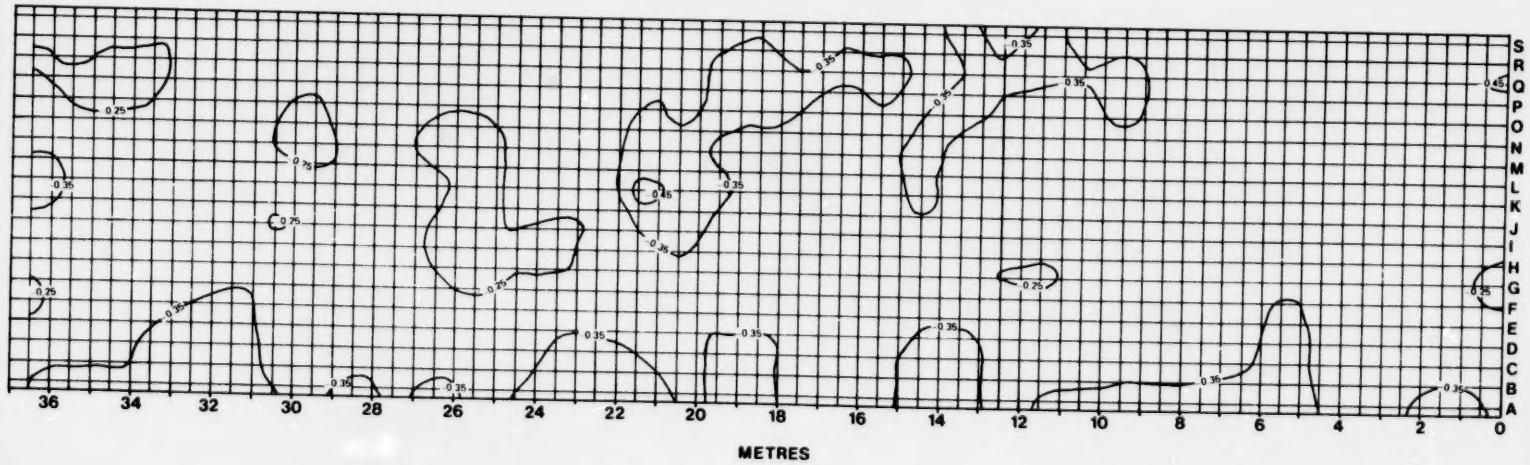


Figure 3/ Pachometer Survey

ALL MEASUREMENTS IN MILLIMETRES

LET	DESCRIPTION	DATE	BY
	REVISIONS		

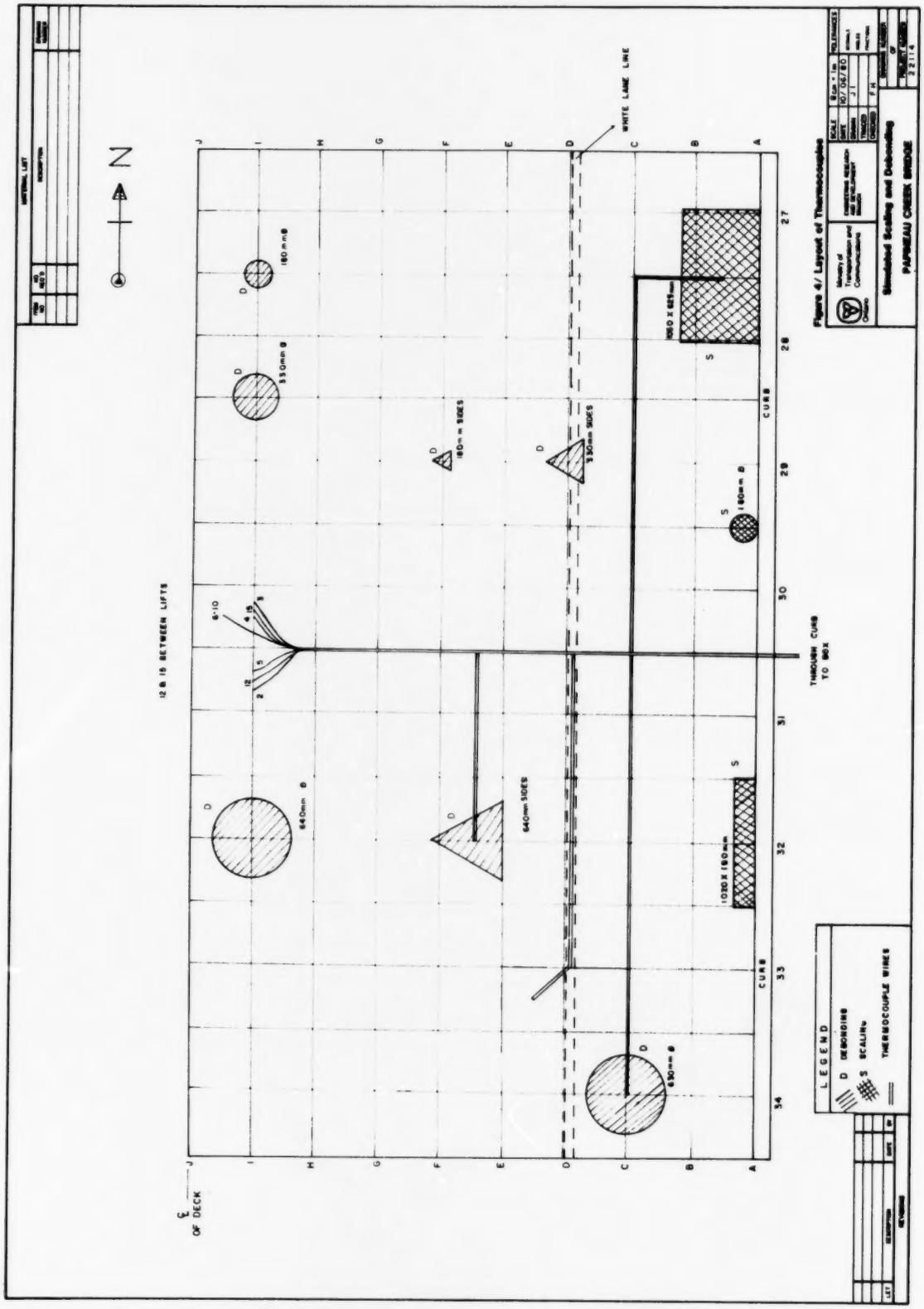
Ontario — Ministry of Transportation and Communications

ENGINEERING RESEARCH AND DEVELOPMENT BRANCH

		TOLERANCES
SCALE	1.5 cm-1 m	DECIMALS
DATE		ANGLES
DRAWN		FRACTIONS
TRACED		
CHECKED		

Pre-Paving Condition
PAPINEAU CREEK BRIDGE

DRAWING NUMBER
OF
PROJECT NUMBER
22114


N
WHITE LANE LINE
180 mm ø
330mm ø
180 mm SIDES
330mm SIDES
1350 X 625mm
180mm ø
640mm ø
640mm SIDES
1020 X 180mm
630mm ø
CURB
THROUGH CURB TO BOX
12 & 15 BETWEEN LIFTS
6-10
LEGEND
D DEBONDING
S SCALING
THERMOCOUPLE WIRES
℄ OF DECK
Figure 4/ Layout of Thermocouples
Ministry of Transportation and Communications Ontario
Simulated Scaling and Debonding
PAPINEAU CREEK BRIDGE
SCALE 8m = 1m
DATE 16/06/80
DRAWN J.T.
CHECKED F.H.
PROJECT 22114

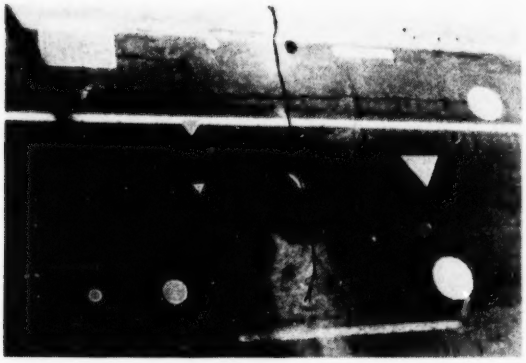


Figure 5/ Masked Areas and Thermocouples In Place Prior to Tack Coat

Figure 6/ Sand and Tack Coat In Place Prior to Paving

Figure 7/ Chain Being Used to Check for Delaminations

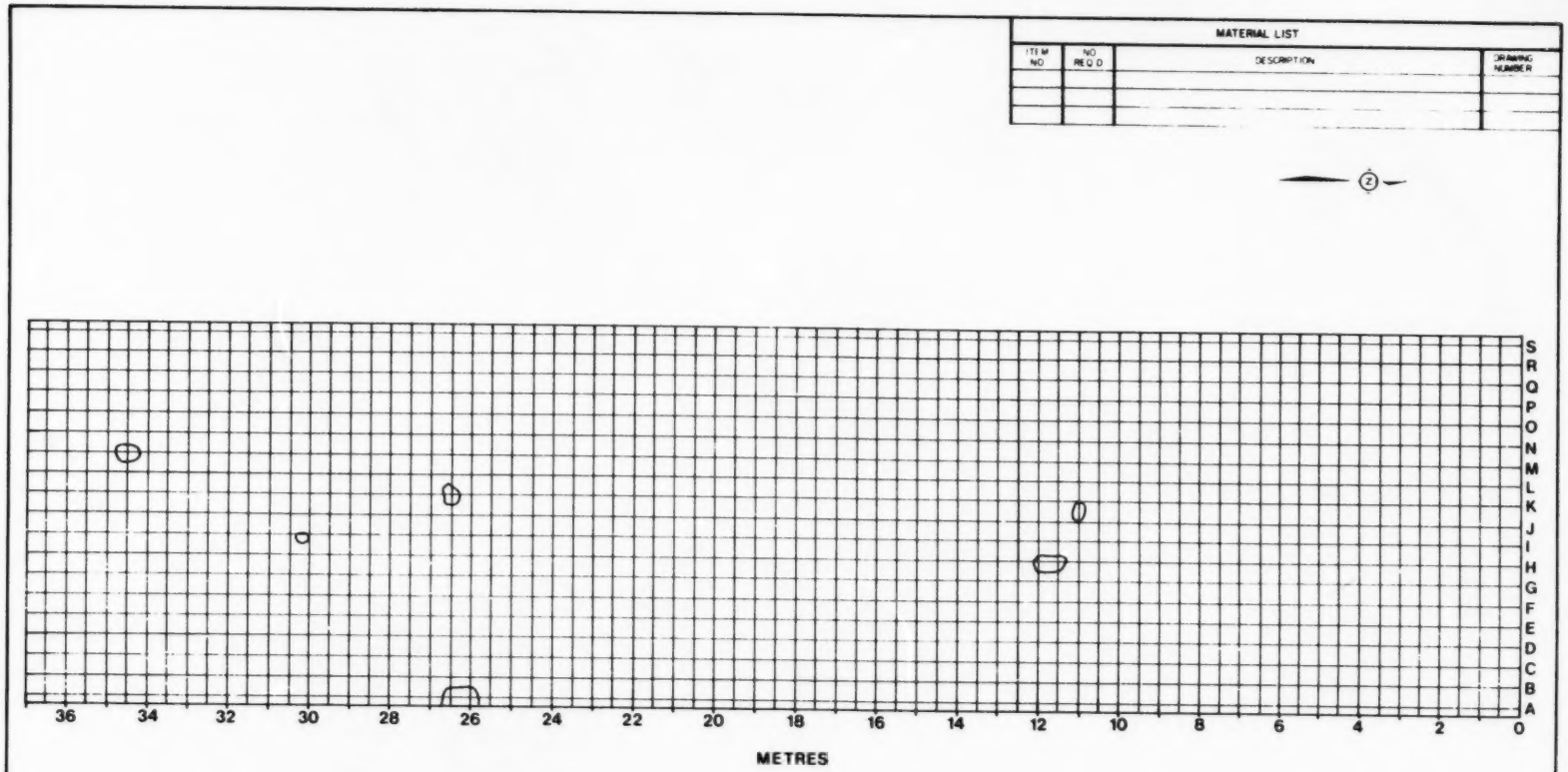


Figure 8/ Delaminations Survey Using Chain-Drag Techniques

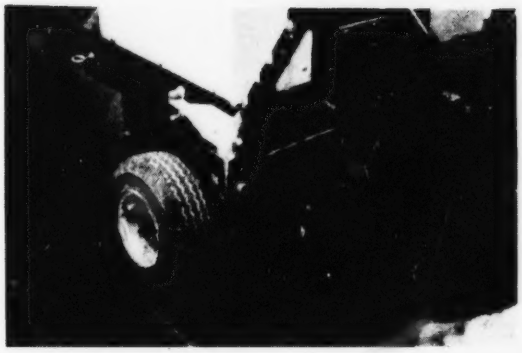


Figure 9a/ Delamtec Showing Tapping Devices and Sonic Transducers

Figure 9b/ Delamtec Two-Channel Pen Recorder

Figure 10/ Delamtec in Operation

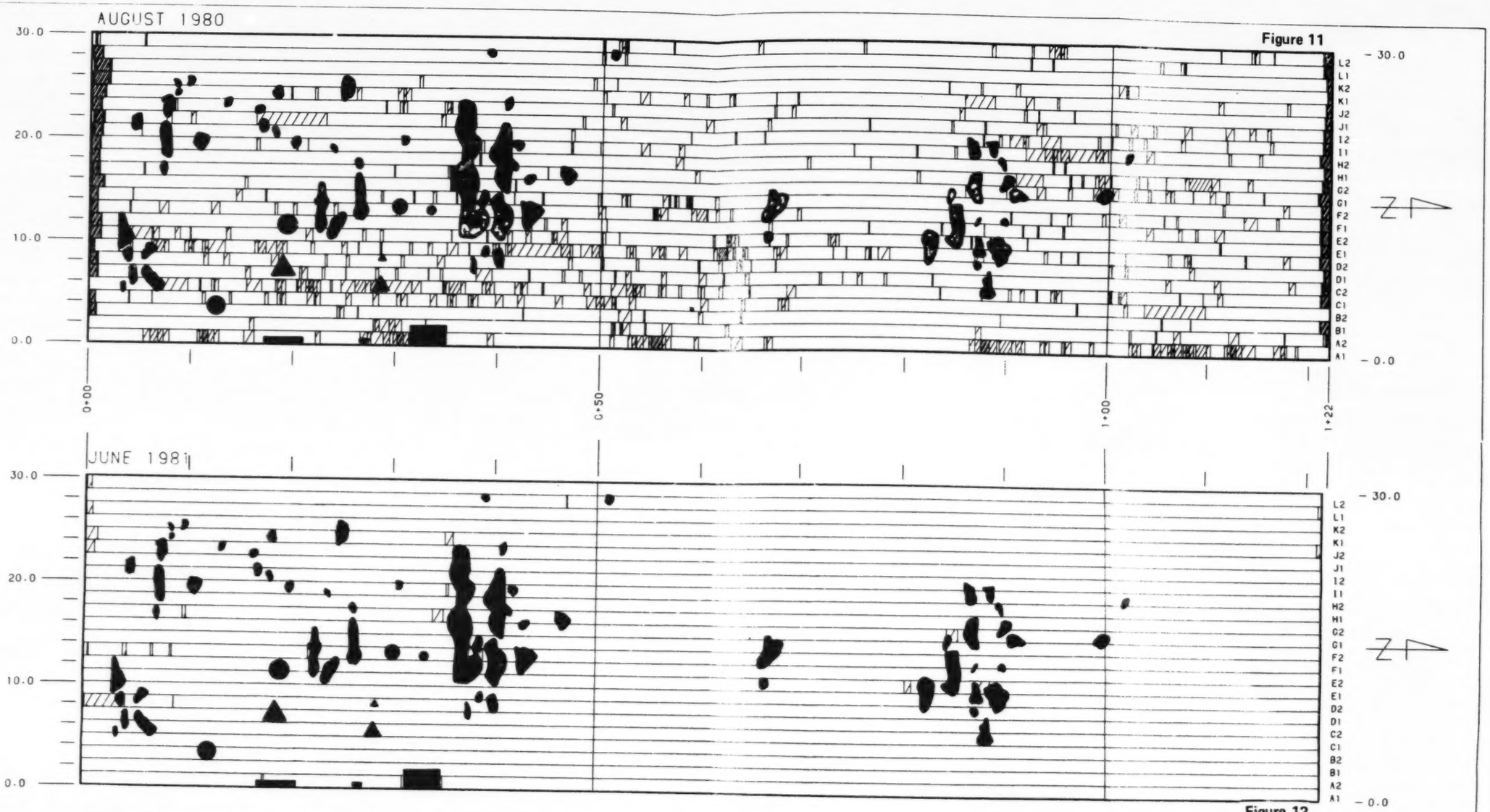


Figure 11

Figure 12

FEDERAL TECHNICAL SURVEYS INC.
DELAMINATION SURVEY
AUGUST 1980/JUNE 1981

- DELAMINATIONS
- SCALING
- DEBONDING

AUTHORITY:	MINISTRY OF TRANSPORTATION AND COMMUNICATION
OWNER:	PROVINCE OF ONTARIO
STRUCTURE:	PAPINEAU CREEK BRIDGE
PLAN NO.:	0001
SCALE:	10 FT./IN.
LENGTH:	122 FT. WIDTH: 30 FT.
AREA-TOTAL:	3660 SQ.FT.

LEGEND:

SYMBOL RANGE OF DELAMTEC SIGNAL

□	A	0- 1.9
▨	B	2- 2.9
▨	C	3- 3.9
■	D	4+
JT		CONST./EXP. JOINTS
BL		BASE LINE

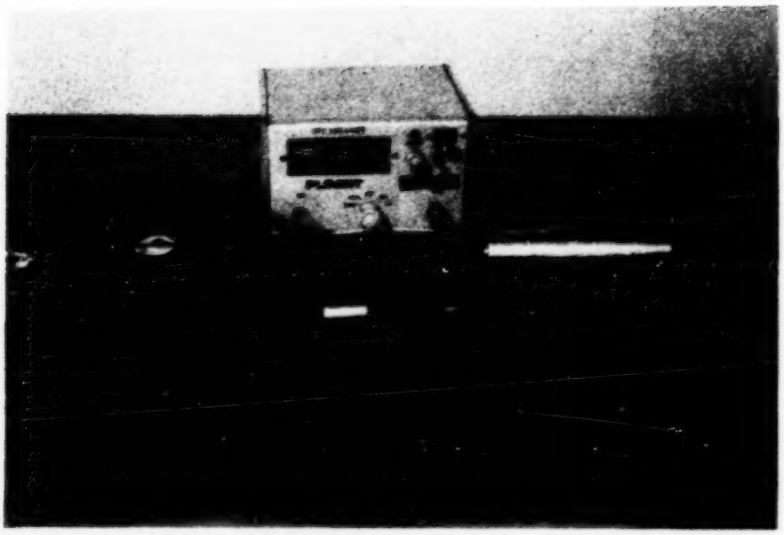


Figure 13/ Pundit Equipment Showing Transducers and Control Unit

Figure 14/ Geometrics-Nimbus ES12-20
Seismograph and Geophones

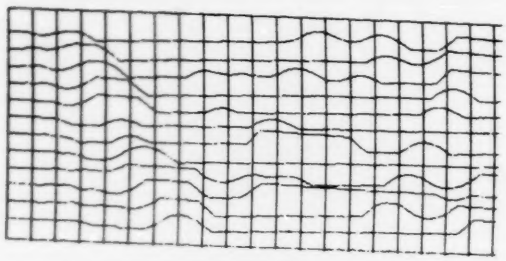


Figure 15/ Seismograph Output
Non-Delaminated Area

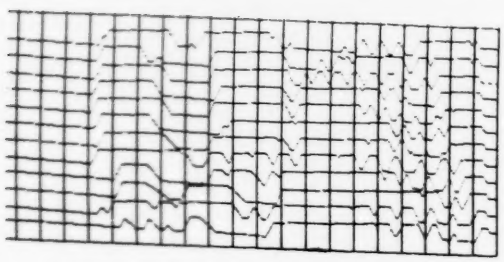
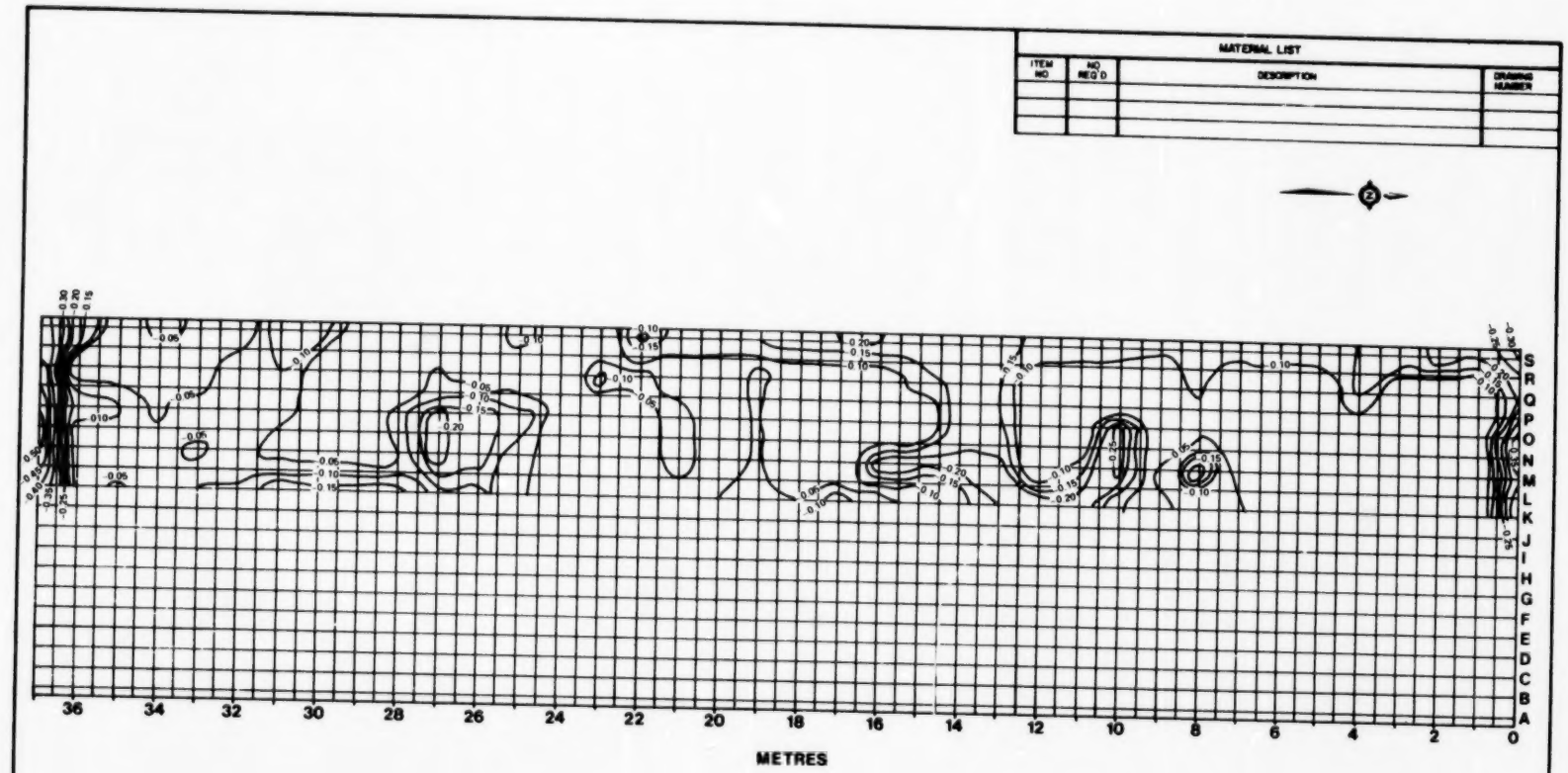


Figure 16/ Seismograph Output
Delaminated Area

Figure 17/ Resistivity Survey in Progress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ITEM NO
NO. REQ'D
DESCRIPTION
DRAWING NUMBER
S R Q P O N M L K J I H G F E D C B A
36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
METRES

Figure 18/ CSE Half-Cell Plot

NOTE: HOLES THROUGH ASPHALT NOT DRILLED

Ministry of Transportation and Communications, Ontario	ENGINEERING RESEARCH AND DEVELOPMENT BRANCH	SCALE: 1.5 cm–1 m	TOLERANCES: DECIMALS, ANGLES, FRACTIONS
		DATE	
		DRAWN	
		TRACED	
		CHECKED	

Post Paving
PAPINEAU CREEK BRIDGE

DRAWING NUMBER OF
PROJECT NUMBER 22114

LET	DESCRIPTION	DATE	BY
	REVISIONS		

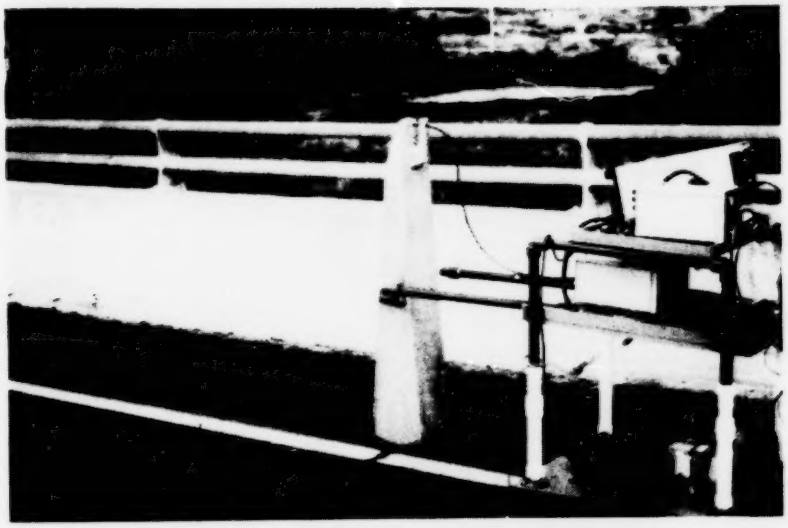


Figure 19/ Penetradar Equipment During Survey

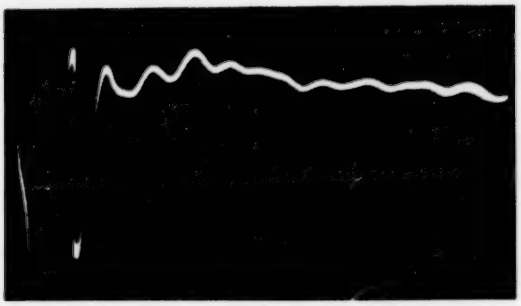


Figure 20/ Typical Radar Signal Trace
for Sound Concrete

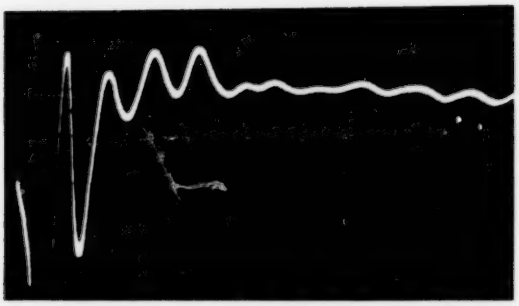


Figure 21/ Typical Radar Signal Trace
for Unsound Concrete

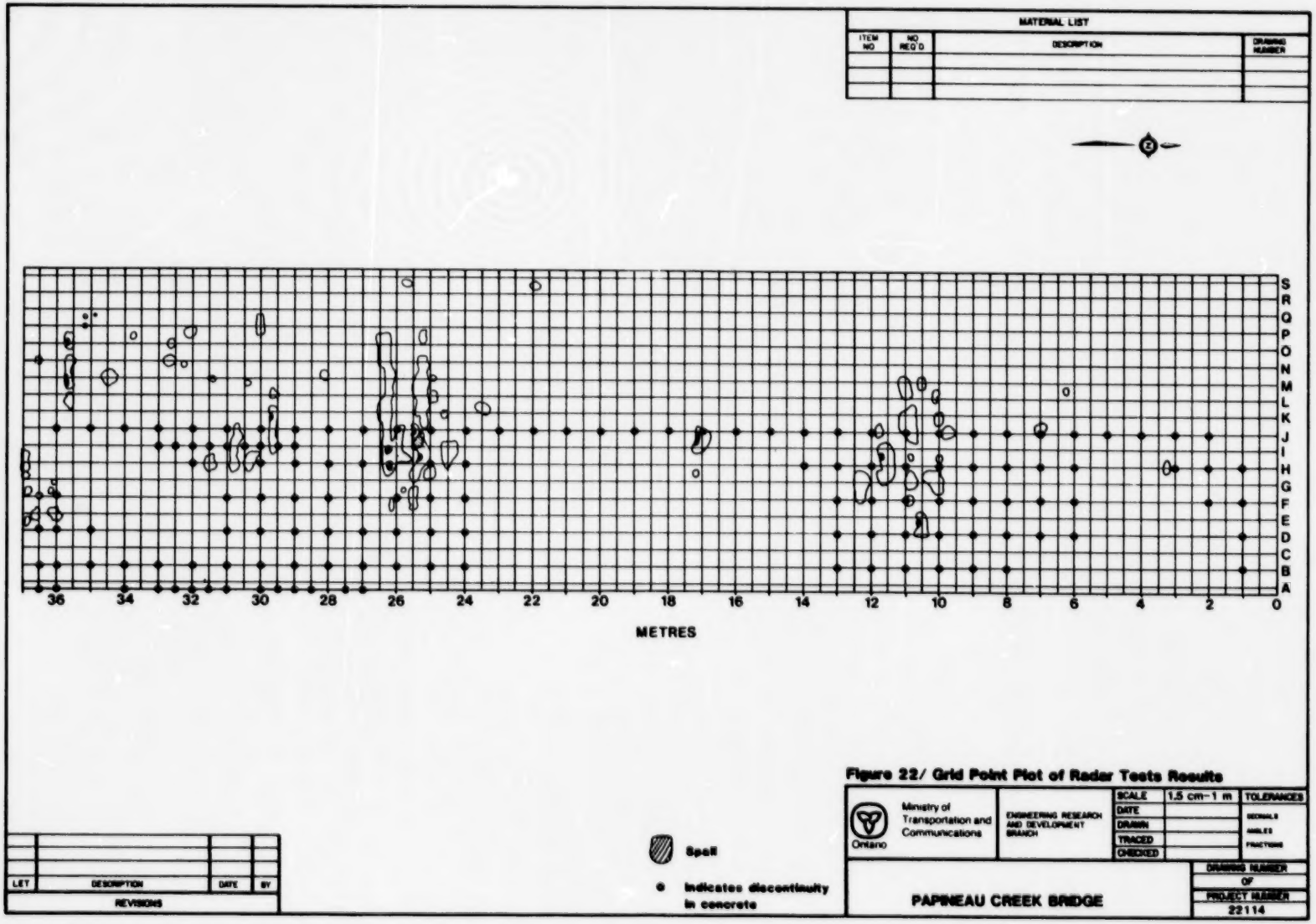


Figure 22/ Grid Point Plot of Radar Tests Results

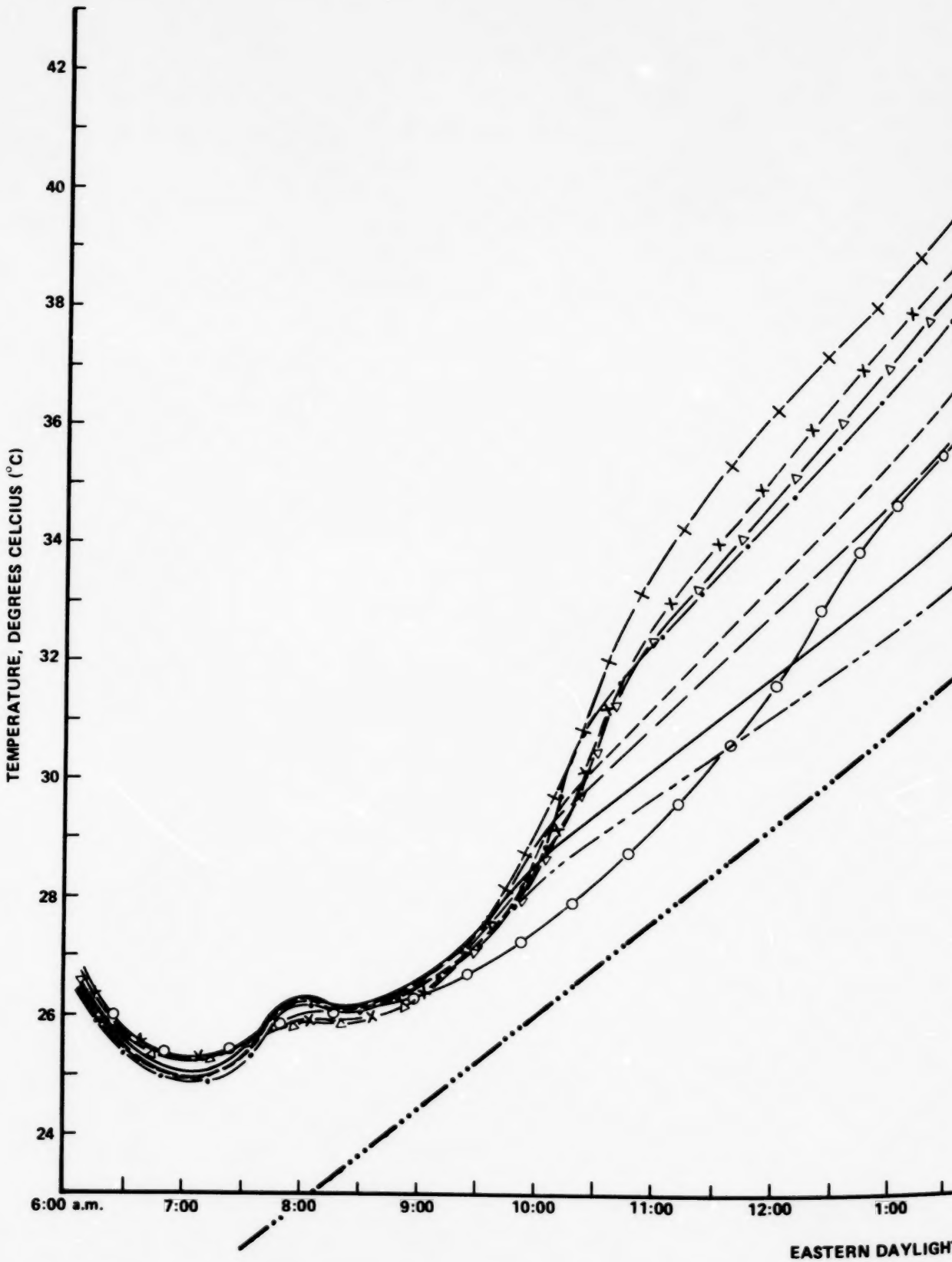
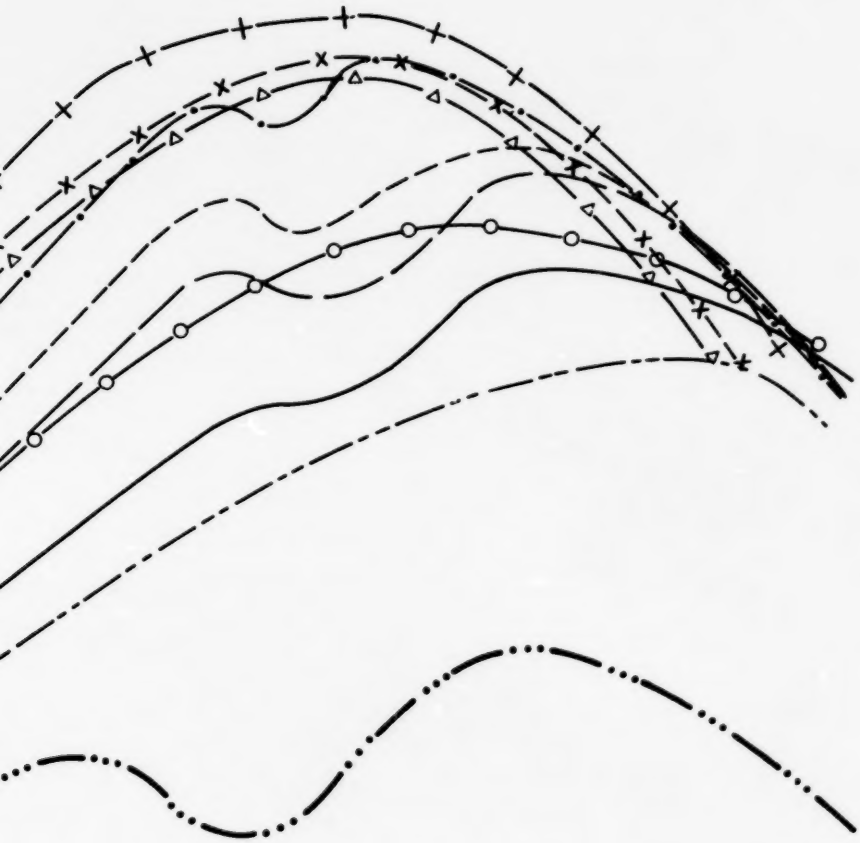


Figure 23/ Temperature Profile Papineau Creek Bridge



—○— THERMOCOUPLE 4 1/4" IN SOLID CONCRETE
—△— THERMOCOUPLE 5 1/4" IN DELAMINATION
—•—• THERMOCOUPLE 6 25 mm IN CONCRETE DECK
– – – – THERMOCOUPLE 7 50 mm IN CONCRETE DECK
—— THERMOCOUPLE 8 75 mm IN CONCRETE DECK
——— THERMOCOUPLE 9 100 mm IN CONCRETE DECK
—– – – THERMOCOUPLE 10 150 mm IN CONCRETE DECK
—+— THERMOCOUPLE 12 BETWEEN LIFTS OVER 5
—×— THERMOCOUPLE 15 BETWEEN LIFTS OVER 4
—•••— AIR TEMPERATURE – SHADE

2:00 3:00 4:00 5:00 6:00 7:00 8:00 p.m.

TIME

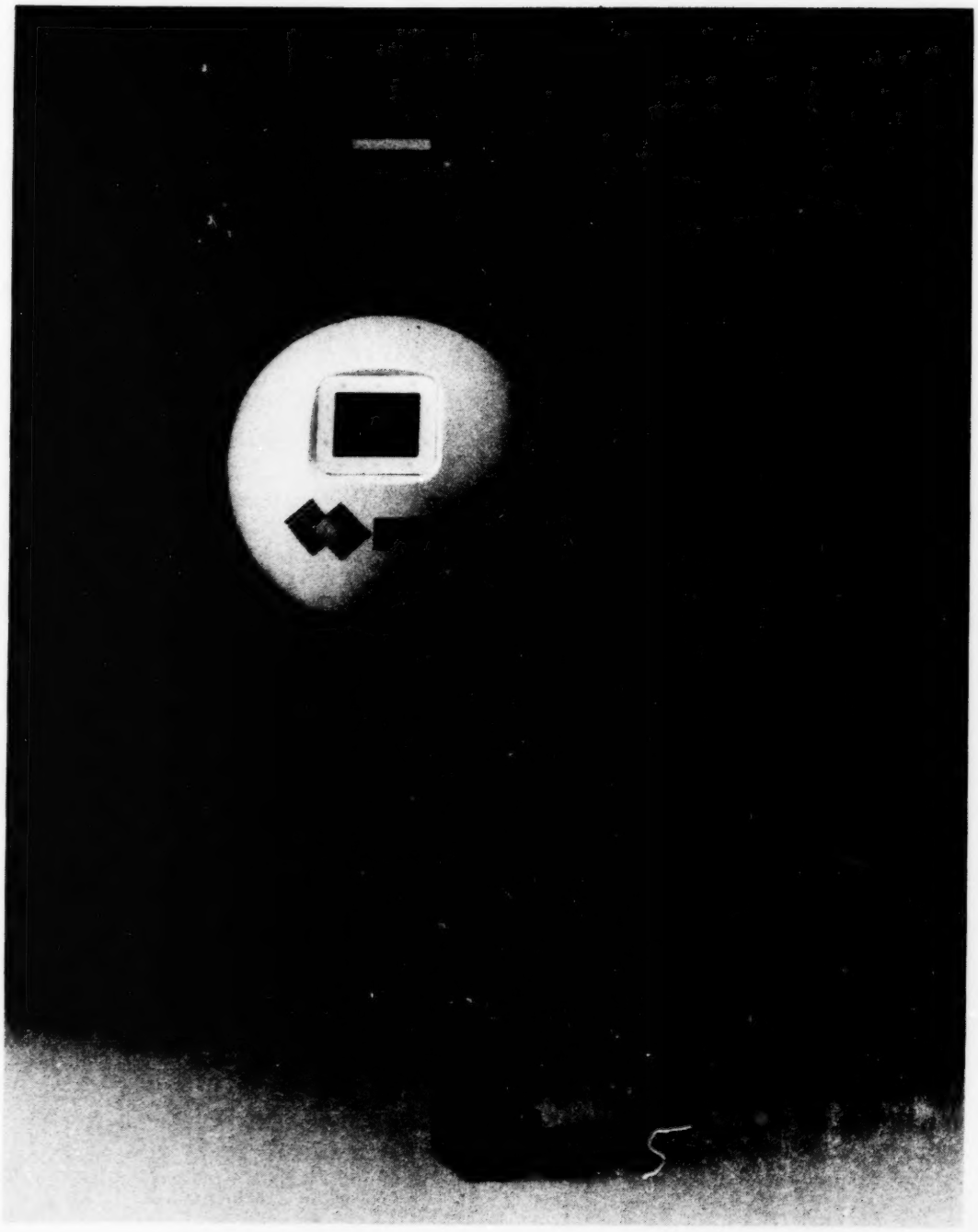


Figure 24/ FLIR System
1/ Scanner
2/ Monitor
3/ Control Unit

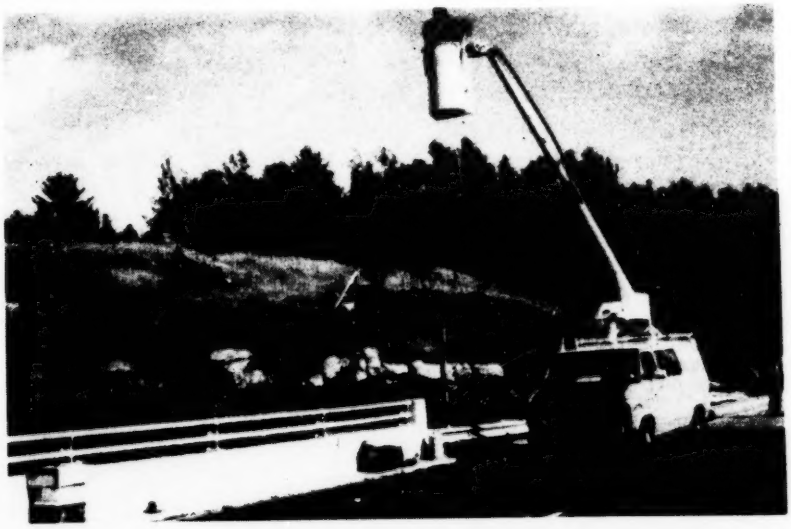


Figure 25a/ Agatronics System 720 Thermovision System
in Operation from Bucket Truck

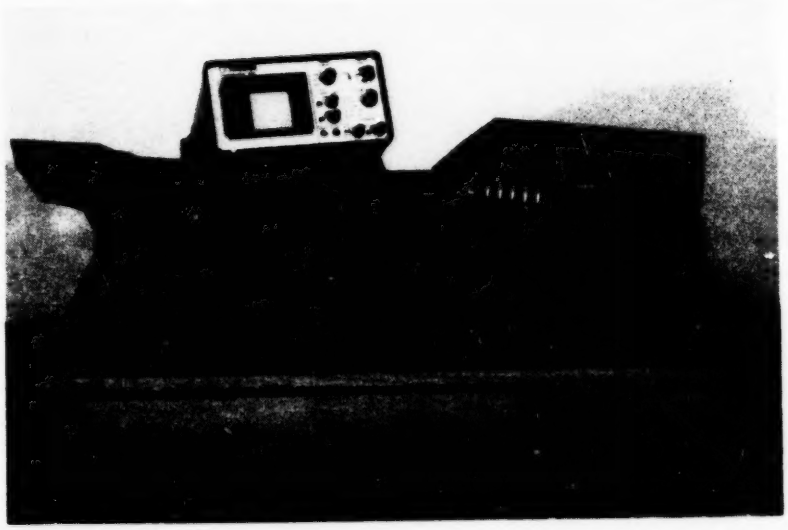


Figure 25b/ Agatronics System 720 Thermovision System
1/ Scanner
2/ Monitor Control Unit
3/ Radar Recorder

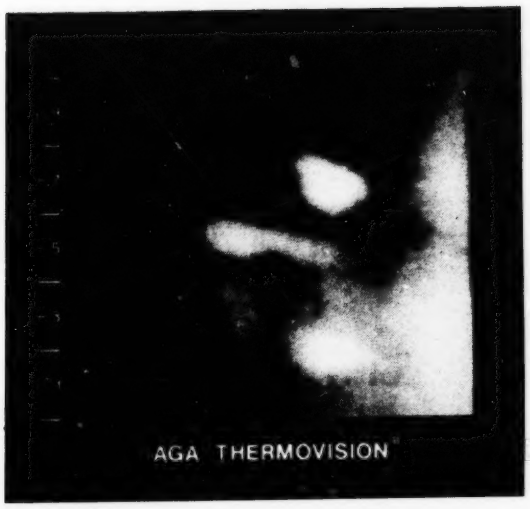


Figure 26/ Thermogram of Grid Area 31-H
Delaminations Appear as White Areas

Figure 27/ Thermogram of Grid Area 13 to 10 - C to J - P
Delaminations Appear as White Areas

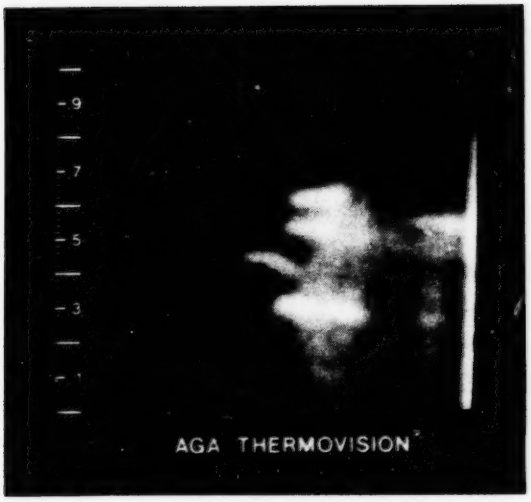


Figure 28/ Thermogram of Grid Area 13 to 10 - C to J
Delaminations Appear as White Areas

Figure 29/ Thermogram of Grid Area 31 to 35 - J to P
Vertical Image of Deck Surface

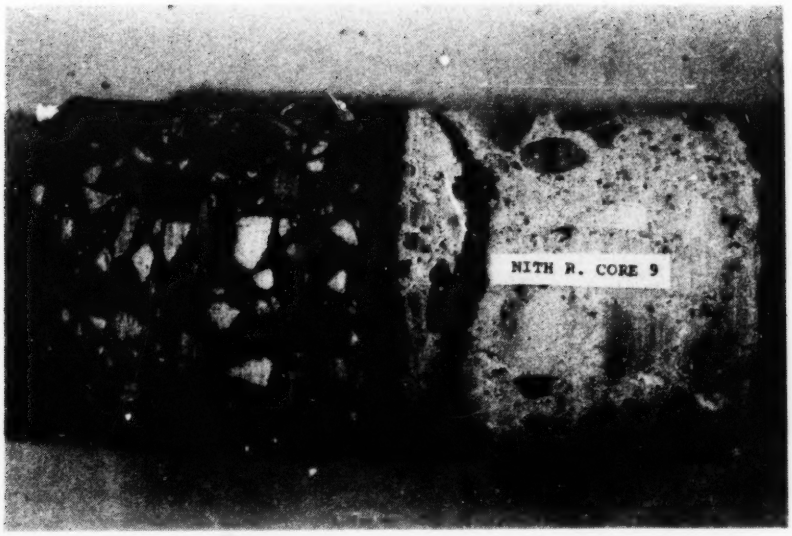


Figure 30/ Core Taken from Nith River Bridge Showing Delamination Below the Asphalt

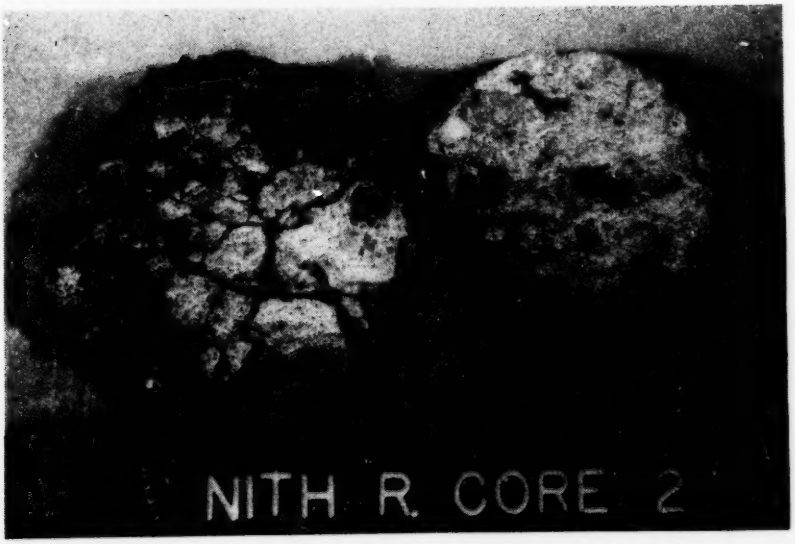


Figure 31/ Core Taken from Nith River Bridge Showing Scaling and Freeze/Thaw Damage Below the Asphalt